A View From **Space**

NASA Systems Engineering and Test

Woody Spring

It has been three years since I witnessed the last Space Shuttle launch, STS-135, lifting off from Earth on July 8, 2011. It was the seventh I had witnessed, but this one had special meaning. Twenty-nine years ago, I was on the inside *looking out* as a part of the STS-23 (STS 61-B) crew. I flew Atlantis on her second flight in 1985 and had observed her construction years earlier at Rockwell International's space shuttle-assembly location.

As a crew, we visited the facility in Palmdale, Calif., where the components were finally assembled. It was an awesome spectacle. This was where a reusable, reliable and incredibly powerful rocket ship called Atlantis came alive. Technology was ubiquitous. There were so many critical components that had to be harmonized. If it weren't for systems engineering and its embedded process imperatives though, the shuttle would have never taken off the ground.

In the last six years, in my capacity as a professor at the Defense Acquisition University, I have found myself reflecting more and more about that day and the importance of Systems Engineering and Test as well as the influence NASA has had on Department of Defense (DoD) weapon system developments.

Technical Necessities Influenced Future Technologies

Like many of DoD's weapon systems, every component on the shuttle experienced decades of experimentation and analysis before it found its home on an operational system: the shuttle. Many key materials and processes didn't even exist, but the shuttle would later depend on them to meet the user's requirements. After all, this newly

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combined air and spacecraft had to blast off with an incredible force (40,320 kilometers per hour or 25,000 miles per hour or 7 miles per second) to escape Earth's gravitational pull, easily maneuver in both subsonic and hypersonic speeds, protect its crew in the cold and unforgiving vacuum of space, and return the crew safely to Earth. The shuttle's exterior had to tolerate temperature extremes colder than Antarctica and hotter than the temperature at which most metals melt. Its crew compartment had to protect its inhabitants from the constant bombardment of radiation.

Needless to say, NASA engineers had to push every operating envelope. Over time and decades of component and full-scale testing, the shuttle took shape. It all came together in a unique form. Aerodynamically, it capitalized on the X-24B lifting body from 1975; NASA adopted a similar winged platform configuration with a comparatively low lift-to-drag ratio like the X-24 that could land accurately without power. Like the X-24, a Space orbiter no longer needed an engine after reentry and would become an unconventional glider, given its maximum landing weight of 230,000 pounds.

NASA instituted technical standards that promoted interoperability among its programs. Since each and every experience in space tended to be groundbreaking, NASA captured engineering lessons learned and proven practices. However, in many cases, NASA engineers had to serve as development pioneers, not to mention perpetual problem solvers. Innovation was always a constant priority. NASA engineers had to infuse technology into solutions to keep costs low without trading away capability or personnel safety. Sound familiar in DoD?

Exploiting Technologies

Since the 1960s when President Kennedy first challenged NASA to send a man to the moon and return him safely to Earth, NASA has produced a tremendous array of technical innovations that have given the United States a noticeable and distinctive advantage. Today our country's national defense development community employs many of NASA's technical accomplishments in numerous weapon systems that continue to help our warfighters maintain a distinctive competitive advantage where it matters the most—on the battlefield.

Unlike Teflon, which was accidentally invented by Roy Plunkett of Kinetic Chemicals in 1938 when he tried to make a new refrigerant and the chemicals polymerized in a pressurized storage container, NASA's developments were carefully guided and cultivated. Some of those gains produced by NASA can be seen in:

- Software
  - Critical Path computer software test and evaluation
  - Semiautonomous and fully autonomous systems and control algorithms
- Robotics: Development of artificial muscle systems with robotic sensing and actuation capabilities for use in NASA space robotic and extravehicular activities that have been adapted to create more functionally dynamic artificial limbs
- Aerodynamic control of inherently unstable platforms (the shape, especially of an aircraft, seen from above)
- Hypersonic platforms
- Aviation safety such as onboard diagnostics and integrated sensing/evaluation/warning
- Self-contained exploration sensors
- Management techniques
  - Technology Readiness Levels (TRLs), with linked Software Readiness and Manufacturability Readiness Levels
  - Configuration control processes
  - Program Requirements Management control
  - Modeling and simulation (M&S)
  - Motion-based trainers
  - Joint integrated simulation at multiple sites
- System of systems architectures
- State-of-the art technologies
  - Microprocessors
  - Component miniaturization
  - Biometrics, solar energy
  - Fuel cells
  - Thin film membrane structures
  - Expandable structures
  - Liquid rockets
  - Dynamic rocket and engine control
  - Astrobiology
  - Environmental monitoring
  - Environmental cleanup and sensing
  - Life support

The countless technical advances NASA achieved also found their way into a wide array of commercial products we use every day back on Earth, including state-of-the-art exercise machines, trash compactors, water filters, smoke detectors, solar and tankless water heaters, quartz clocks, bar codes, smaller digital cameras, complementary metal oxide semiconductor chips and technology used in cell phones, cameras, webcams, digital image stabilization, insulating material and other means.

When law enforcement officials needed help improving a grainy crime scene video, NASA assisted with the high-tech image-processing technology it used to analyze space shuttle launch video. NASA also seeded some major industry leaders with game-changing technologies. Goodyear Tire and Rubber Company produced a radial tire with a tread life expected to be 10,000 miles greater than conventional radials by using a fibrous material it developed for NASA.

Process Ruled the Day

As I stood watching the countdown clock for Atlantis, I also remembered the importance of technical and management processes. They ruled the day. Those integrated processes that NASA and DoD share provide a methodology for designing and realizing systems—and for planning,

The author manipulates a structure during the second Extra Vehicular Activity from the Space Shuttle Atlantis.
NASA photo.

assessing and controlling the technical development effort as it evolves.

As astronauts, we practiced every process step along the pathway to ensure all system functions responded to our human actions as intended. Just as it did before, the thousands of coded exchanges that took place between Launch Control Center the day I left Earth in 1985 and the last time the shuttle left Earth on July 8, 2011, affirmed whether every key component could safely "go for launch."

If any component operated outside its performance envelope, "built-in" holds immediately surfaced and delayed the launch until the issue was fully addressed. The tight coupling of technical and management processes that was exercised beforehand reduced the likelihood of lifting off with an unresolved issue.

Diverse Teams Can Overcome Adversity

At high school, West Point, Navy Test Pilot School, my Test Pilot group at Edwards Air Force Base and in Vietnam, I noticed early the significance of teams and the tremendous outcomes they achieve working as a unit. From ground crew to mission crew, the NASA team members were incredibly professional and mission-focused as well as being leading experts in their fields. My astronaut experience reinforced this lesson even more. We learned from our combined knowledge and experience. We benefited from our diversity in much the same way that DoD's acquisition integrated process and product teams do today.

At NASA, we knew we had to depend on each other during our qualification process. We practiced everything over and over until it became second nature. For more than eight years, I had the good fortune to participate in this amazing NASA dynamic that could respond to any technical or leadership challenge, no matter what conditions prevailed. Sad to say, the dangerous nature of space exploration yielded a few tragedies resulting in the loss of wonderfully dedicated and accomplished Americans.

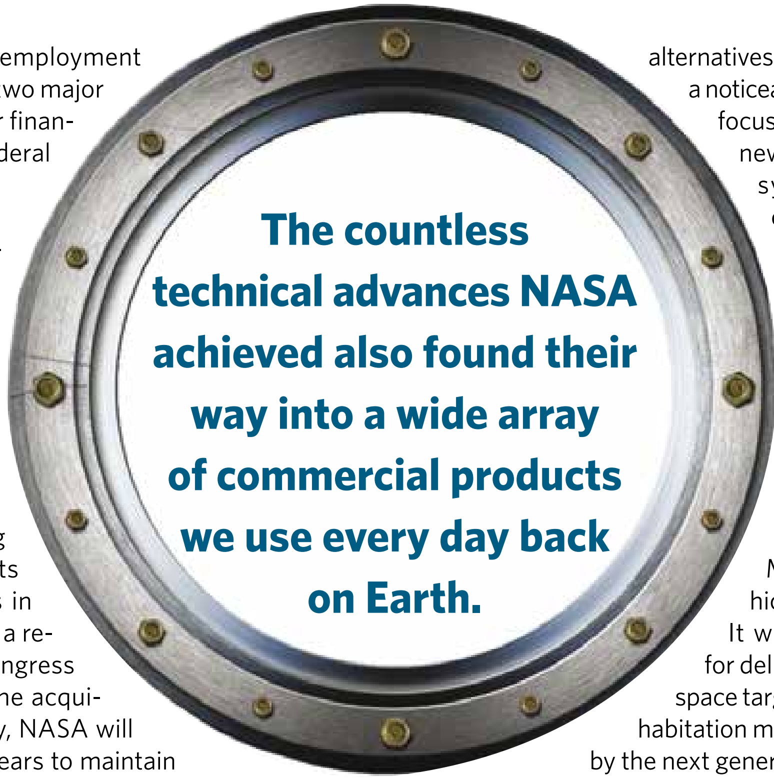
Two shuttle accidents, several aircraft vehicle accidents, and the same medical conditions we all face outside NASA struck some of my NASA colleagues. Every one of them made their mark on history and will forever be remembered by helping make space travel safer and more meaningful.

The Experience Quotient

Technical experience in both DoD and NASA takes time to develop. After the shuttle program formally ended, many of the personnel faced a different kind of fate in the form of impending unemployment. The end of the shuttle era also meant numerous subordinate programs reached the end of their lives as well.

Nevertheless, as the mission at NASA evolved just like it did after the Apollo program ended in 1972, managers worked to place personnel in other jobs and/or explore retraining opportunities. Many of these workers had been supporting the shuttle program since their 20s. Now, with the shuttle program ending, they were in their 50s. Retraining and relocating at this age proved difficult and uncertain for some.

About 30,000 aerospace engineers and support personnel were at risk. The unemployment numbers were an equal concern for other industries across the country. But since 1960 NASA has never seen human capital challenges like those



> **The countless technical advances NASA achieved also found their way into a wide array of commercial products we use every day back on Earth.**

of today. The national unemployment rate, growing deficit, and two major wars have created greater financial pressures for every federal agency, including NASA.

In the mid-1990s, the Defense Acquisition Workforce was cut in half for a number of reasons, including outsourcing. This cutback was expected to create huge efficiencies and savings. There were also many unintended consequences, including serious experience deficits in the government ranks in the following decades. As a result, in 2008 the U.S. Congress passed a law to rebuild the acquisition workforce. Similarly, NASA will be tested in the coming years to maintain its foundation of experience to avoid a similar outcome. Experience matters in every career field, especially systems engineering and test.

The Frontier Forward

When our nation retired the space shuttle, an American icon recognized and envied around the world as the symbol for space over the last quarter-century became history. Is the future of America's leadership in space at risk? NASA faced a similar challenge in the early 1970s when Congress canceled the last three Apollo moon missions with little notice, leading to a major gap in a U.S. launch capability. NASA used one Apollo Saturn V rocket system to build and launch Skylab, but then watched Skylab de-orbit after three missions.

The United States found itself with no launch capability to reboost Skylab to a stable orbit and no gap filler. The shuttle's operational deployment was too late to help. Now, after 30 years of spectacular service, the shuttle is no longer safe to use without a major update of multiple systems. Absent an expensive life-extension program, system reliability was well below acceptable levels for the shuttle.

Like the challenge in the early 1970s, no replacement system is ready to fill the gap in time. With our nation's weapons systems, we had to make equally tough choices but could not afford certain critical operational gaps that would jeopardize warfighting capability. As a result, many of today's weapon systems are in service well beyond their expected life. These include the B-52, which first saw service in 1955.

NASA has decided to get out of the business of Low Earth Orbit (LEO) launch operations because industry and commercial ventures are expected to become more economical alternatives. Space X has already taken a noticeable lead. NASA will instead focus beyond LEO and incubate new technologies. Invariably, systems engineering will continue to predominate.

NASA has two new exciting programs under consideration and tentative development—a Crew Capsule and a heavy lift Space Launch System (SLS). The crew capsule will have a deep space capability with a Multi-Purpose Crew Vehicle (MPCV) and seat four. It will be the primary vehicle for delivering astronauts to deep-space targets. It will also mate with a habitation module and can be launched by the next generation commercial systems or SLS. NASA continues with creative innovation in multiple product lines reinforcing American leadership in next generation technologies similar to what the United States enjoyed following Apollo.

Conclusion

The United States needs to make hard choices if NASA is to send astronauts to an asteroid by 2025, and a crewed Mars mission by the 2030s. Game-changing technologies are still a necessity; and key processes and experience will continue to rule the day. In the DoD, we could not win the nation's wars without them either.

As we look to NASA to field the brainpower and expertise that drives its high-powered, innovative, diverse and multifunctional teams, I remember that as Americans we have an insatiable thirst for technical solutions. I witness it in class every day in my current role as a DAU professor training DoD's acquisition workforce members along their certification pathway.

So, am I concerned about NASA or the acquisition community overcoming their challenges? Not one bit. It's how we are wired as Americans and pioneers, no matter what career we pursue. We just need to make sure we remind ourselves of our potential with some frequency. That and proper funding will keep us unbeatable.

I remember lying on my back in Atlantis 29 years ago going through the countdown check list. As we did in those days, Atlantis launched on time too—a perfect record in my book. Timing is everything; funding is critical—and a little luck helps.

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